치의과학박사 학위논문

Effects of anaerobic sealing agents on preload of implant abutment screw

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2020년 8월

서울대학교 대학원

치의과학과 치과보철학 전공

류 승 범

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이 논문을 류 승 범 박사학위논문으로 제출함

2020년 5월

서울대학교 대학원

치의과학과 치과보철학 전공

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류승범의 박사학위논문을 인준함

2020년 7월

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Abstract

Effects of anaerobic sealing agents on preload of implant abutment screw

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Purpose: The purpose of this study was to evaluate the preload of the abutment screw when using anaerobic sealing agents in implants and abutment screws. Specifically, the study examines the effects of anaerobic sealing agents on different types of abutments and over time.

Materials and Methods: External hexagon implants (Osstem, Seoul, Korea) made of titanium and hex or non-hex abutments were used. Titanium abutment screws from the same manufacturer were used. Medium-strength ([MS], Loctite 242, Henkel, Düsseldorf, Germany)

and high-strength ([HS], Loctite 243, Henkel, Düsseldorf, Germany) anaerobic sealing agents were applied to the implant/abutment screw interfaces. The implant-abutment assemblies were divided into six groups (n = 10 in each). In the control group (CG), no sealing agent was used at the implant/abutment screw interfaces. The control groups were composed of hex (H-CG) and non-hex (NH-CG) abutments. The other four groups consisted of a combination of abutment structures and sealing agents: hex abutment and medium-strength anaerobic sealing agents (H-MS); non-hex abutment and medium-strength anaerobic sealing agent (NH-MS); hex abutment and high-strength anaerobic sealing agent (H-HS); non-hex abutment and high-strength anaerobic sealing agent (NH-HS). All abutment screws were tightened to 30 N·cm, according to the manufacturer's recommended instructions. After applying the sealing agent, the removal torque (i.e., detorque) value of each screw was measured using a digital torque gauge device at 0h(immediately) and 24, 48, 72, 96h. The data were analyzed using Welch's ANOVA, two-way repeated-measures ANOVA, one-way ANOVA and Tukey's HSD tests, according to normality distribution satisfaction.

Results: For 24, 48, 72 and 96h in each group, the mean detorque values are in the following order: H-CG: 20.3 ± 1.60, 20.1 ± 1.84, 20.0 ± 1.15, 19.8 ± 1.21; NH-CG: 20.2 ± 1.40, 20.0 ± 1.09, 20.1 ± 0.762, 19.8± 1.51; H-MS: 25.0 ± 2.86, 25.1 ± 4.18, 27.1 ± 5.19, 27.3 ± 2.52; NH-MS: 23.5 ± 2.35, 25.9 ± 3.06, 29.2 ± 2.65, 29.6 ± 2.47; H-HS: 32.4 ± 6.75, 32.6 ± 4.34, 31.8 ± 5.26, 31.9 ± 3.76; NH-HS: 19.1 ± 1.05, 28.8 ± 6.06, 31.4 ± 3.63, 33.9 ± 5.37, 35.0 ± 4.50 N·cm. Comparison at 24h showed that the groups using anaerobic sealing agents had higher detorque values than the control group ($P < .05$). From 24 to 96h, the HS groups had a higher detorque values than the MS groups. The results were measured immediately after applying sealing agents and tightening: H-CG: 20.1 ± 0.843; NH-CG: 20.1 ± 0.599; H-MS: 19.6 ± 1.78; NH-MS: 19.7 ± 1.33; H-HS: 19.1 ± 1.07; NH-HS: 19.1 ± 1.05 N·cm. There were no statistically significant differences were among all groups ($P > .05$).

Conclusion: Within the limitations of this study, the following conclusions can be drawn.

1. At 24h, the removal torque values were higher in the groups that used anaerobic sealing agents than in the control groups. There were no statistically significant differences between hex abutment and non−hex abutment groups.
2. From 24 to 96h, the HS groups had higher removal torque values than the MS groups.
3. From 24 to 96h, the removal torque values gradually increased with time in the groups using anaerobic sealing agents and non−hex abutments.
4. From 24 to 96h, the removal torque values were no statistically significant differences in the groups using anaerobic sealing agents and hex abutments.
5. There were no statistically significant differences in the immediate measurement of the removal torque values in all groups.

Keywords : anaerobic sealing agent, abutment screw, screw removal torque, preload

Student number : 2017−39738

CONTENTS

I. INTRODUCTION

An implant-supported prosthesis replaces a lost natural tooth and plays an important role in modern dentistry. An implant prosthesis consists of three parts: the fixture, the abutment, and the abutment screws. Although there are various implant-abutment connection designs, the screw design is most common.[1]

An implant-supported prosthesis can either be screw- or cement-retained.[2] Screw-retained prostheses can be readily retrieved, easily repaired. However, the presence of screw holes on the occlusal surface of the prosthesis affects occlusion and esthetics.[3] All implant systems, screw- or cement-retained, use screws to connect the implant and the abutment.

Despite high success rates in screw-retained implant-supported prostheses, screw loosenings or screw fractures are common.[4] Priest[5] observed that after 10 years of implant placement, 7.1% of screw loosening occurred. Jung et al.[6] reported loosening of the holding and abutment screws at a rate of 12.7% in implant placement after five years. Furthermore, loosening of abutment screws creates micro-motion and micro-gap in the implant-abutment assembly, which causes micro-leakage and results in biological complications.[7, 8]

Screw loosening occurs in two stages. First, when the screw receives external forces (transverse or lateral) during the masticatory function, the preload reduces due to a decrease in the tension of the implant threads. Second, the tensile force decreases below the threshold value, and the thread is rotated by external force and vibration, resulting in screw loosening.[9] This screw loosening can cause screw fractures, prosthetic fractures, loss of osseointegration, and fracture of implants.[13] Screw loosening can be caused by external factors such as improper implant placement and occlusal relationship, crown geometry, excessive bite force, insufficient tightening torque, and inadequate prosthesis fit. It can also be caused by internal factors such as loss of tension due to a decrease in the tension of the screw itself.[10, 11]

Screw loosening also occurs due to an excessive force applied to the screw joint or vibration of bolted joints.[12-14] Thus, the friction coefficient and preload are directly related and inversely proportional.[14-16] There are various methods to prevent screw loosening: changing the length of the screw on the abutment, the shape of the threads and valleys, the position and number of threads, or changing the roughness of the screw surface.[17] Other methods include increasing the passive fit of the prosthesis or increasing the number of implants, eliminating occlusal interferences and reducing the occlusal surface area, and increasing the contact surface with the adjacent teeth.[18]

Lubricants or adhesives can be used to change the friction coefficient of the abutment screw and the threads inside the implant.[19] Various studies[20, 21] have introduced sealing agents to fill the space between implants and abutment screws. Silicone sealants, anaerobic sealing agents, and cyanoacrylate-based adhesives were used in the studies.[20, 21] Among them, studies on anaerobic sealing agents observed high removal torque (i.e., detorque) by reducing preload loss.[20, 21]

In this study, anaerobic sealing agents were used. High-performance polymerizable anaerobic sealants originated in 1953 and are used to lock metal parts together chemically.[22] Anaerobic sealants, thermosetting industrial adhesives that polymerize rapidly in the absence of air, are primarily based on esters of acrylates and methacrylates.[23] Anaerobic sealing agents are curing in anaerobic conditions, and the degree of activation depends on the surface of the material and time.

Anaerobic sealing agent manufacturers[24] provide materials with curing time and degree suitable for metals such as steel, copper, and zinc. They suggest that curing is completed after 24h. The manufacturers provide data up to 72h based on M10 steel bolts and nuts, and breakaway strength gradually increases with time up to 72 h. After 72h, copper showed a fixed strength of about 60% compared to full fixed strength on steel. In addition, other materials showed strength of less than 75% and strengths of various values. Therefore, the degree of curing is expected to vary depending on the material properties and surfaces. However, there is insufficient information on differences in the types of implant abutments or curing on titanium surfaces, which are frequently used in dental implant prosthesis. Although the manufacturer proposed that complete curing was achieved after 24 h on M10 steel bolts and nuts,[24] the conditions for complete curing differed depending on the material, and there was no time−dependent data on the titanium surface of the dental implant prosthesis. In the study[25] of the mechanical engineering field for anaerobic sealing agents, it was observed that hardening progressed up to 96 h in the case of steel, and therefore, changes in time up to 96h were observed in this study.

The purpose of this study was to evaluate the preload of the abutment screw when using anaerobic sealing agents in implants and abutment screws. Specifically, the study examines the effects of anaerobic sealing agents on different types of abutments and over time.

II. MATERIALS AND METHODS

1. Implants and abutments

The implants and abutments from Osstem Co. (Seoul, Korea) were prepared for this study. External hexagon implants (USII, 4.0 x 11.5 mm, Osstem, Seoul, Korea) were used (Fig. 1A).

Titanium abutments with hex ([H]) or non-hex ([NH]) structures (D: diameter 5.0mm, G/H: gingival height 2.0mm and H: height 4.0mm, Osstem, Seoul, Korea) were used (Fig. 2). Titanium abutment screws from the same manufacturer (Osstem, Seoul, Korea) were used (Fig. 1B).

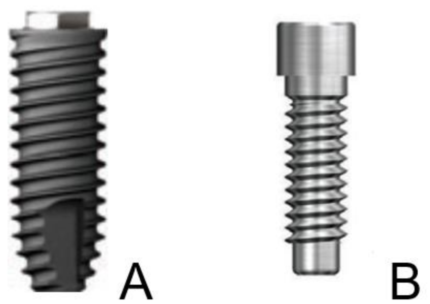

Figure 1. (A) External hexagon implant(USII, 4.0 x 11.5 mm, Osstem, Seoul, Korea), (B) Abutment screw(Osstem, Seoul, Korea).

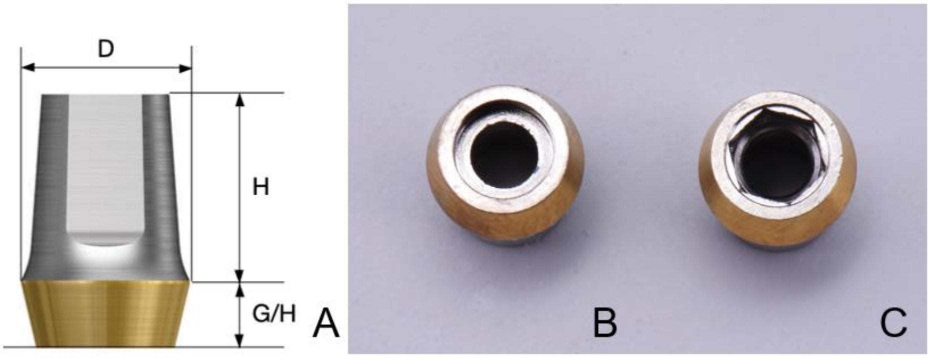

Figure 2. (A) Abutment (D: diameter, 5.0mm; H: height, 4.0mm; G/H: gingival height, 2.0mm; Osstem, Seoul, Korea), (B) Axial view of non-hex abutment, (C) Axial view of hex abutment.

2. Anaerobic sealing agents

The anaerobic sealing agent is curing in an oxygen-blocking environment. There are two types of sealing agents – one that can be loosened by hand using a tool, and the other one is disassembled by using a torque wrench in a hot state after partial heating up to 260℃ or higher. The agent that can be loosened by hand was used in the experiment. Medium-strength anaerobic sealing agent ([MS]; Loctite 242, Henkel, Düsseldorf, Germany) and high-strength anaerobic sealing agent ([HS]; Loctite 243, Henkel, Düsseldorf, Germany) were used.

According to the manufacturer, MS is composed of 60–70% polyethylene glycol dimethacrylate (Fig. 3), 1–10% modifier, 1–10% amorphous fumed crystalline−free silica, 1–3% alkyl hydroperoxide, and 1–10% glycol.[24] The main components of HS are as follows: 10–30% tetramethylene dimethacrylate, 1–5% amorphous fumed silica, 1–5% ethene (homopolymer), and 1–5% propane−1,2−diol. MS is a dilute solution with flow characteristics, and HS has a high viscosity, dark color, and does not flow.

The anaerobic sealing agents were applied very carefully to the abutment screws in order to control the amount of sealing agent. Using flocked applicator tip (2mm, Manufacturer No. 60667198, Dentsply DeTrey GmbH, North Carolina, USA), the anaerobic sealing agents were applied twice to the abutment screws, to fill the threads of the abutment screws, except for the top 3 −4 threads (Fig. 4).

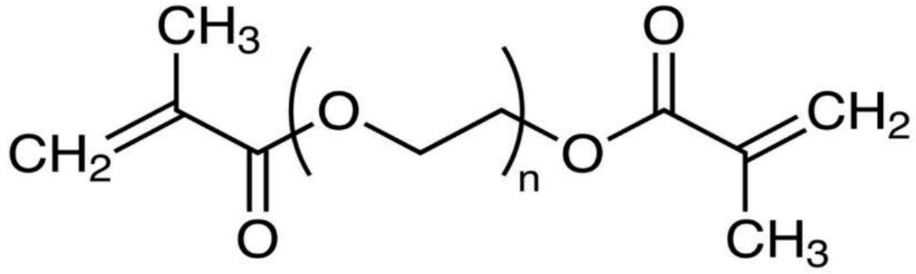

Figure 3. The structural formula of polyethylene glycol dimeth-acrylate, which consists the anaerobic sealing agent ([MS]; Loctite 242, Henkel, Düsseldorf, Germany), n=4 (usually).

Figure 4. Abutment screw (Osstem, Seoul, Korea) (A) Control,
(B) Application of medium strength anaerobic sealing agent ([MS]; Loctite 242, Henkel, Düsseldorf, Germany), (C) Application of high strength anaerobic sealing agent ([HS]; Loctite 243, Henkel, Düsseldorf, Germany).

3. Setting up the experimental group

The implant−abutment assemblies were divided into six groups, with 10 assemblies in each group.

1) H−CG group: hex abutments without sealing agents([CG], control group) on the implant/abutment screw interfaces.
2) NH−CG group: non−hex abutments without sealing agents([CG], control group) on the implant/abutment screw interfaces.
3) H−MS group: hex abutments and medium−strength anaerobic sealing agents.
4) NH−MS group: non−hex abutments and medium−strength anaerobic sealing agents.
5) H−HS group: hex abutments and high−strength anaerobic sealing agents.
6) NH−HS group: non−hex abutments and high−strength anaerobic sealing agents.

4. Abutment screw tightening apparatus

A specimen clamping tool was used to hold implants. The implants were clamped into the clamping tool, composed of collet and nut (Nikken Kosakusho Works, Osaka, Japan), along the taper of the implant and this clamping tool was connected to the stainless steel base (Fig. 5).

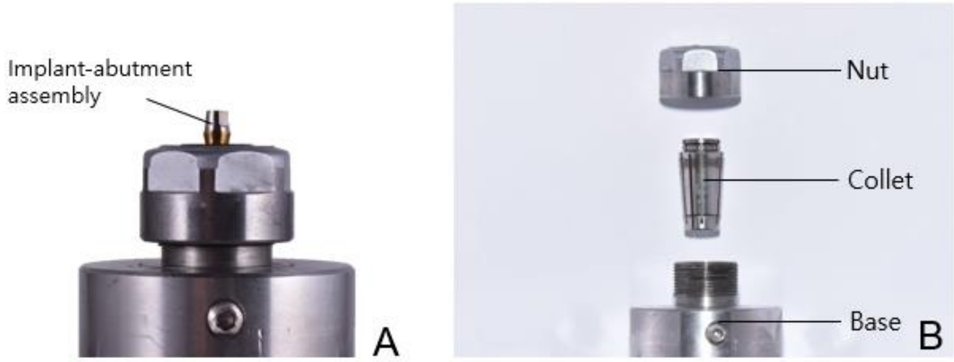

Figure 5. (A) Implant–abutment assembly clamped with an implant holder (Nikken Kosakusho Works, Osaka, Japan), (B) Detailed internal structure of the clamping tool (Nut, Collet, and Base).

The implant and the abutment were assembled using an abutment screw, which was tightened to 30 N·cm with a contra–angle torque device (Torq Control Ref. 15000, Anthogyr, Sallanches, France), according to the manufacturer's recommendations (Fig. 6).

Figure 6. Contra angle torque device (Torq Control Ref. 15000, Anthogyr, Sallanches, France).

5. Measurement of removal torque value

Detorque values were measured using a digital torque gauge (MGT50, Mark-10 Co., Hicksville, NY, USA) (Fig. 7). A driver of the 1.2 hex standard from the same manufacturer as the screw, was connected to the digital torque gauge. The detorque values were measured by one person.

Figure 7. Digital torque gauge (MGT50, Mark-10 Co., Hicksville, NY, USA).

After applying the sealing agent to the abutment screw, it was tightened to 30 N·cm, according to the manufacturer's recommendation. The detorque values of each screw were measured after tighening, at a temperature of 23 ± 1 °C. No sealing agent was used in the CG, and the abutment screws were initially tightened to 30 N·cm.

6. Removal torque Measurement over time

The manufacturer suggested that curing occured after 24h, and each group was compared through measurement data at 24h. Subsequently, changes in removal torque up to 24, 48, 72, 96h were measured at each hour and therefore, each group was compared. The statistical processing of the data measured at each hour and the percentage changes were analyzed.

7. Removal torque measurement at 0h

The initial effects of the viscosity of anaerobic sealing agents were evaluated. In this study, anaerobic sealing agents may initially act as lubricants. The anaerobic sealing agent is viscous in nature. MS tends to be thin and flowing, while HS does not flow due to high viscosity. Detorque values were measured immediately after applying sealing agents and tightening in all groups.

8. Statistical analysis

Statistical analyses were performed using the The R Project for Statistical Computing(R foundation, Vienna, Austria) and SPSS 26 (IBM® SPSS® Statistics, IBM Co., NY, USA). The data were analyzed by Welch's ANOVA and Dunnett T3 test, two-way repeated-measures ANOVA, one-way ANOVA and Tukey's HSD(Honestly Significant Difference) tests according to normality distribution satisfaction as observed through the Shapiro-Wilk test and Q-Q plot. The significance level was set at 0.05. Welch's ANOVA test and Dunnett T3 were performed for comparison after 24 h. A two-way repeated-measures ANOVA test was used for comparison over time, and a one-way ANOVA test was performed when detorque values were measured immediately after applying anaerobic sealing agents.

III. RESULTS

1. Removal torque measurement at 24h

The anaerobic sealing agent manufacturer suggests that curing is completed after 24h. When comparing 24h data in Table 1 the data were satisfactory in the normality distribution but not homoscedasticity, and were tested using Welch's ANOVA test. As a result, both hex and non-hex showed differences by groups. When combining Dunnett T3 post hoc analysis results and the graph, the detorque values of groups were significant, and CG < MS, HS ($P < .05$). Compared to CG, at 24h, the data showed an increased detorque values, H-MS: 22.9%, NH-MS: 16.3%, H-HS: 59.4%, and NH-HS: 42.3%. There was no statistical significance between the MS and HS groups ($P > .05$). When the same sealing agent was used, there were no statistically significant differences in the groups using hex abutments and non-hex abutments ($P > .05$). The higher increase in detorque values was observed in the hex abutment groups than in the non-hex abutment groups.

2. Removal torque measurement at 0, 24, 48, 72, and 96h

For 0, 24, 48, 72, and 96h in each group, the mean detorque values are in the following order (Table 1, Fig. 8, Fig. 9),

1) H-CG: 20.1 ± 0.843, 20.3 ± 1.60, 20.1 ± 1.84, 20.0 ± 1.15, 19.8 ± 1.21 N·cm
2) NH-CG: 20.1 ± 0.599, 20.2 ± 1.40, 20.0 ± 1.09, 20.1 ± 0.762, 19.8± 1.51 N·cm
3) H-MS: 19.6 ± 1.78, 25.0 ± 2.86, 25.1 ± 4.18, 27.1 ± 5.19, 27.3 ± 2.52 N·cm
4) NH-MS: 19.7 ± 1.33, 23.5 ± 2.35, 25.9 ± 3.06, 29.2 ± 2.65, 29.6 ± 2.47 N·cm
5) H-HS: 19.1 ± 1.07, 32.4 ± 6.75, 32.6 ± 4.34, 31.8 ± 5.26, 31.9 ± 3.76 N·cm
6) NH-HS: 19.1 ± 1.05, 28.8 ± 6.06, 31.4 ± 3.63, 33.9 ± 5.37, 35.0 ± 4.50 N·cm

Table 1. Mean values (standard deviation) of removal torque values (N·cm) over time according to MS, HS groups and hex, non-hex abutments combination

Time (h)	Group					
	H-CG	NH-CG	H-MS	NH-MS	H-HS	NH-HS
0	20.1 (0.843)	20.1 (0.599)	19.6[a] (1.78)	19.7[b,c] (1.33)	19.1[d] (1.07)	19.1[e,f] (1.05)
24	20.3 (1.60)	20.2 (1.40)	25.0[a] (2.86)	23.5[b,c] (2.35)	32.4[d] (6.75)	28.8[e,f] (6.06)
48	20.1 (1.84)	20.0 (1.09)	25.1 (4.18)	25.9[b,c] (3.06)	32.6 (4.34)	31.4[e,f] (3.63)
72	20.0 (1.15)	20.1 (0.762)	27.1 (5.19)	29.2[b] (2.65)	31.8 (5.26)	33.9[e] (5.37)
96	19.8 (1.21)	19.8 (1.51)	27.3 (2.52)	29.6[c] (2.47)	31.9 (3.76)	35.0[f] (4.50)

H-CG = control group using hex abutment, NH-CG = control group using non-hex abutment; H-MS = hex abutment and medium strength anaerobic sealing agent; NH-MS = non-hex abutment and medium strength anaerobic sealing agent; H-HS = hex abutment and high strength anaerobic sealing agent; NH-HS = non-hex abutment and high strength anaerobic sealing agent. [a,b,c,d,e,f] Letters represent the statistically significant differences ($P < .05$).

There were two different types of abutments and sealing agents used, where each component interacted with others. Each data value followed the normality distribution. Therefore, two-way repeated-measures ANOVA test was conducted at four time points (24, 48, 72, 96h). The statistical significance of time was tested in all groups regardless of hex and non-hex groups. From Mauchly's sphericity test results to confirm the sphericity hypothesis, the probability is about 0.577, which satisfies the spherical shape at the significance level of 0.05. There were a statistically significant differences in detorque values in the MS and HS groups (H-CG, NH-CG < H-MS, NH-MS < H-HS, NH-HS; $P < .05$). Regardless of abutment type, Tukey's HSD was performed by post hoc analysis because the number of implant-abutment assemblies per experiment were the same. Detorque values tended to increase with time, and the 24h-72h, 24h – 96h differences and the 48h – 72h, 48h – 96h differences were significant at $P < .05$.

As the patterns were different over time between the hex and non-hex groups, each group was divided into two-way repeated-measures ANOVA tests. In both cases, the spherical assumption was satisfied through the Mauchly's sphericity test, and a post-hoc test was performed through the Tukey's HSD test. For hex abutments, there were no statistically significant differences in detorque values over time ($P > .05$). All treatment with anaerobic sealing agents showed significant results (H−CG < H−MS < H−HS; $P < .05$). In the case of non−hex abutments, there were statistically significant differences over time ($P < .05$). All results were significant except for 72 h – 96 h. Similar to the hex group, the effects of sealing agents existed between groups (NH−CG < NH−MS < NH−HS; $P < .05$). On dividing hex and non−hex abutments into MS and HS groups, the results charts are as follows (Fig. 8, Fig. 9):

The trend over time from 24h to 96h for each sealing agent was different in non−hex and hex abutments. The hex group showed consistent detorque values, however, the non−hex group showed a tendency to gradually increase with time.

In all the groups, except for the CG group, detorque values increased when anaerobic sealing agents were applied from 0h to 96h in hex and non−hex abutment ($P < .05$). In the case of the control group, there was no change in detorque values with time ($P > .05$).

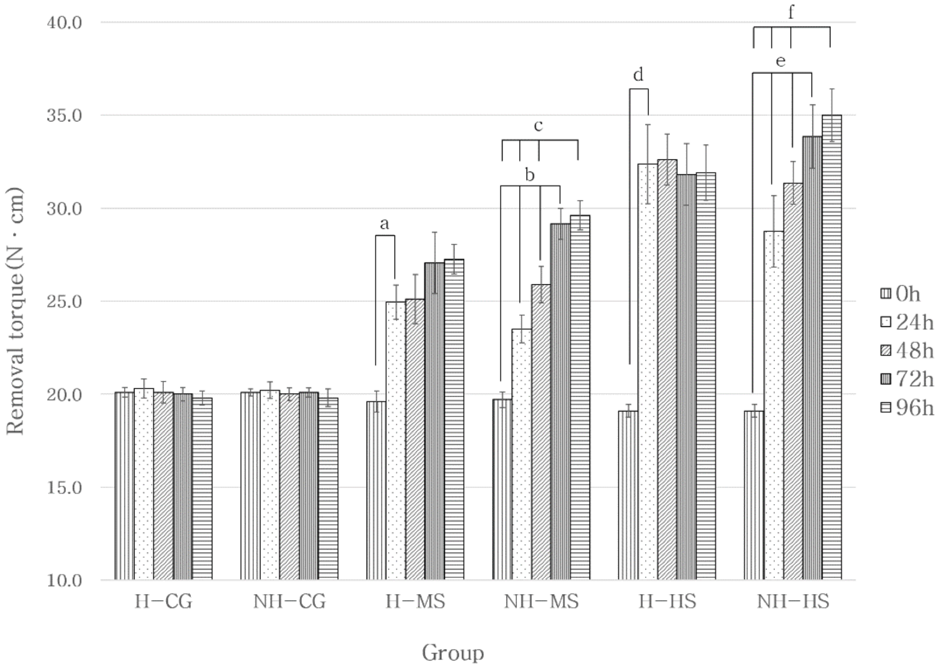

Figure 8. Mean removal torque values for each group at 0, 24, 48, 72, and 96h. [a,b,c,d,e,f] Letters represent the statistically significant differences ($P < .05$).

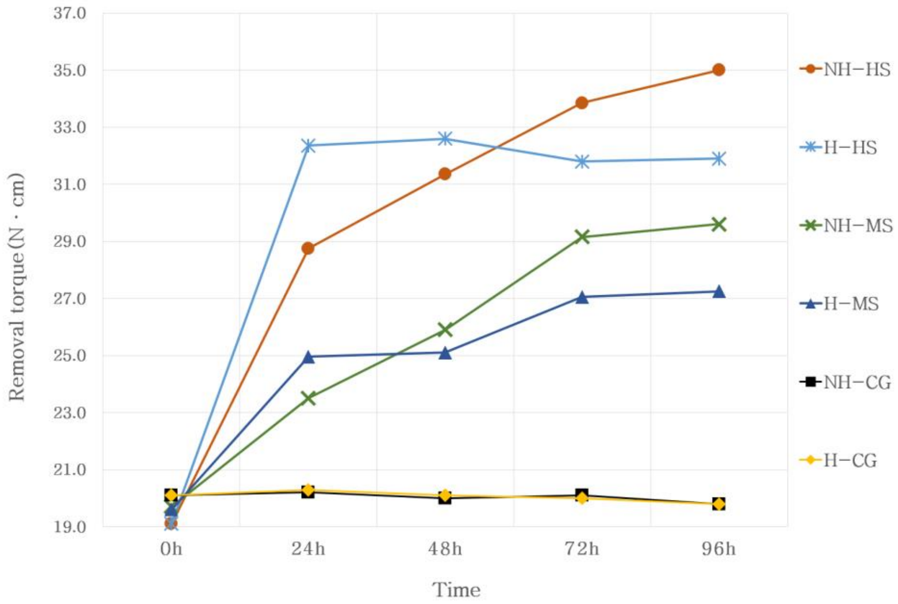

Figure 9. Mean removal torque values indicated by a linear graph for each group at 0,24,48,72, and 96h.

At the time points of 0, 24, 48, 72 and 96h in each group, the results of change rate in detorque values in H−MS, H−HS and NH−MS, NH−HS when compared with each control group (H−CG, NH−CG), that were divided according to each abutment, were as follows (Table 2), H−MS(0,24,48,72,96h in order): −2.49, 22.9, 24.9, 35.3, 37.5 %; NH−MS: −1.99, 16.3, 29.5, 45.0, 49.5 %; H−HS: −4.98, 59.4, 62.2, 59.0, 61.1 %, NH−HS: −4.98, 42.3, 56.8, 68.4, 76.8 %.

Table 2. The percentage of change rate in removal torque values compared to H−CG, NH−CG over time according to MS, HS groups and hex, non−hex abutments combination.

Time (h)	Group			
	H−MS	NH−MS	H−HS	NH−HS
0	−2.49	−1.99	−4.98	−4.98
24	22.9	16.3	59.4	42.3
48	24.9	29.5	62.2	56.8
72	35.3	45.0	59.0	68.4
96	37.5	49.5	61.1	76.8

H−MS = hex abutment and medium strength anaerobic sealing agent; NH−MS = non−hex abutment and medium strength anaerobic sealing agent; H−HS = hex abutment and high strength anaerobic sealing agent; NH−HS = non−hex abutment and high strength anaerobic sealing agent. The hex([H])abutment groups were compared to H−CG as control, and non−hex([NH])abutment groups compared with NH−CG.

When sealing agents were treated at 0h, the decrease rate was shown because the detorque values decreased. After 24h, the detorque value increased by at least 16.3%. In the case of 24, 48h, the increase rate of H−HS was the highest, but after 96h, NH−HS showed the highest increase rate as the detorque value increased to 76.8% compared to NH−CG.

3. Removal torque measurement at 0h

The experiment was conducted to determine the effect of the sealing agent viscosity on detorque values immediately after abutment tightening. Similar to the experiment over time, the test was conducted on the hex abutment, non−hex abutment, MS, and HS combinations. Detorque measurements immediately after tightening for each group are as follows (Fig 10, Table 3), H−CG: 20.1 ± 0.843; NH−CG: 20.1 ± 0.599; H−MS: 19.6 ± 1.78; NH−MS: 19.7 ± 1.33; H−HS: 19.1 ± 1.07; NH−HS: 19.1 ± 1.05 N·cm.

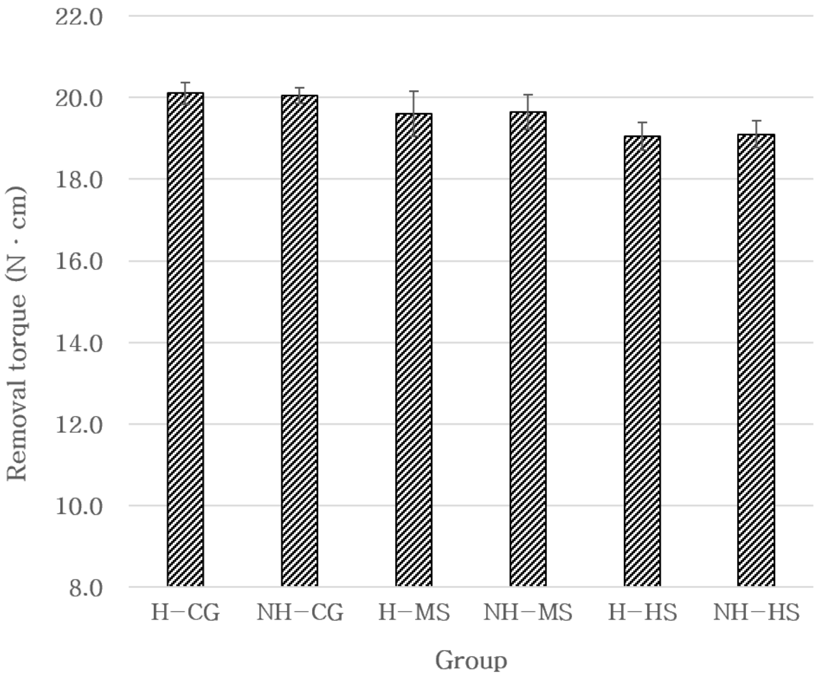

Figure 10. Mean removal torque values for each group. The results were measured immediately after applying sealing agents and tightening. There were no statistically significant differences among all groups ($P > .05$).

Table 3. Mean removal torque (standard deviation) values (N·cm) measured immediately after applying sealing agents and tightening, for each group.

Group					
H−CG	NH−CG	H−MS	NH−MS	H−HS	NH−HS
20.1	20.1	19.6	19.7	19.1	19.1
(0.843)	(0.599)	(1.78)	(1.33)	(1.07)	(1.05)

H−CG = control group using hex abutment, NH−CG = control group using non−hex abutment; H−MS = hex abutment and medium−strength anaerobic sealing agent; NH−MS = non−hex abutment and medium−strength anaerobic sealing agent; H−HS = hex abutment and high−strength anaerobic sealing agent; NH−HS = non−hex abutment and high−strength anaerobic sealing agent. There were no statistically significant differences among all groups ($P > .05$).

When the sealing agents were applied to the abutment screws and immediately loosened, the Shapiro–Wilk normality test showed that each group had a normal distribution. At the significance level of 0.05, the data in each group followed normality. Moreover, the Bartlett test for homogeneity of variances satisfied the homoscedasticity in the 0.05 level of significance. As mentioned above, the experimental results satisfied the normality distribution. In one–way ANOVA test, there were no statistically significant differences in detorque values among all groups ($F = 0.315$, $P > .05$).

IV. DISCUSSION

The abutment screw is an essential component that connects the implant abutment and the implant. The implant−abutment assembly is maintained due to the mechanical force of the abutment screw.[26] In general, A screw is tightened at the torque recommended by the manufacturer. When a screw is tightened, the tensile force is created between the threads inside the implant and the abutment screw threads,[9] defined as preload. The preload is influenced by the following factors: tightening torque, screw components, screw design, and friction coefficient.[10]

The preload shows positive correlations with the tightening torques for screws. As the screw functions in a state of elastic deformation, tightening to a higher torque beyond the elastic limit does not necessarily mean higher preload. When the preload exceeds the yield limit of the abutment screw material, the screw is permanently deformed and loses its function, resulting in screw deformation or fracture. Therefore, the ideal preload is usually 60%−80% of the yield strength of the material.[11, 27−29]

Detorque, also called removal or reverse torque, was assumed to be the preload remaining in the screw.[14, 30−33] When the detorque value was measured after 0, 24, 48, 72, and 96h in the control group, there was no statistically significant difference, but the mean detorque value was slightly lower in the 96h group. This is because the preload maintained by friction and tension decreases naturally over time. [11, 29]

The results show that anaerobic sealing agents have a positive effect on the elevation of detorque values in the implant−abutment assemblies. In the MS group, compared with the CG, detorque increased by 37.5% (in 96h, H−MS). and the HS group increased by 61.1% (in 96h, H−HS) compared to CG. It is considered as one of the methods to increase the stability and suppress the reduction of preload in the abutment screw.[30] In this study, detorque was measured to evaluate the stability of screw−retained prosthesis when the sealing agents were applied to the implant/abutment screw interfaces. If the detorque value is higher or similar to the tightening torque, the prognosis for the screw−retained prosthesis is better.[30, 34]

Anaerobic sealing agent manufacturers suggest complete curing after 24h.[24] At 24h, the removal torque values were higher in the groups that used anaerobic sealing agents than in the control group ($P < .05$). Depending on the conditions, it was observed that anaerobic sealing agents were curing even after 24h on the abutment screw. The detorque values tended to increase with time when the non-hex abutment was used. These results suggested that the non-hex abutment groups took longer for curing of sealing agents. There are a structural differences between hex and non-hex abutments, as shown in Figure 2. Hex abutment resists vertically and horizontally on the fixture platform, in contrast, non-hex abutments are not resistant to rotation on the fixture platform. Due to the above differences in abutments, the curing of the anaerobic sealing agents over time was different. At 24h, there were no statistically significant differences between hex abutment and non-hex abutment groups ($P < .05$). However, when the same sealing agent was used, a higher detorque values were increased in the hex abutment groups than in the non-hex abutment groups. In the results after 72h, when the same sealing agent was used, the groups using non-hex abutments showed higher values than those using hex abutments.

The differences from 24h to 96h for hex abutment were not statistically significant in both MS and HS groups. However, Detorque values of H−HS group tended to decrease after 72h. The remaining high strength anaerobic sealing agents after the complete curing on abutment screw, implied the decrease in elasticity of sealing agents after 72h. These effects were assumed to contribute to the detorque value reduction.

The curing of anaerobic sealing agents is activated under anaerobic conditions. In the initial stages, the sealing agents may act as a lubricant to reduce detorque. Because of the presence of viscosity in the sealing agents themselves, this viscosity can increase or decrease the initial loosening torque.[35] At 0h(immediately), detorque values were measured by tightening to 30 N·cm with the contra−angle torque device and loosening after 30 seconds using the digital torque gauge. The results showed no statistically significant differences among all groups. However, in the results, detorque values were decreased in the MS and HS groups compared to the control groups, and in the case of hex or non−hex abutments, a 2~2.5% decrease in the MS groups and a 5% decrease in the HS groups were observed when compared to the control groups.

The abutment screw was tightened to 30 N·cm according to the manufacturer's recommendation and a torque driver was used for fastening. Among the four representative torque controllers (torque limiting device, torque indicating device, contra angle torque driver, and electronic torque controller), the most precise contra angle torque driver was used.[36]

The manufacturers of typical anaerobic sealing agents suggest applying a few drops to the thread at the appropriate dosage. The United States Department of Defense standard suggests applying completely to the screwed joint, but over-application is likely to occur in the above cases.[24, 37] As the results may differ depending on the amount of sealing agent applied to the screw threads, the efforts were made to quantify the amount applied. If the sealing agent is applied to all the threads of the screw, it overflows and sticks to the other parts, making it difficult to evaluate only the effect of the sealing agents between threads. Therefore, excluding the upper 2– 3 threads of screw, the sealing agents were applied to the threads of the screw so that they only fill the valley between threads, without overflow (Fig. 4). This minimizes the effect of the sealing agent overflowing when tightening.[38] If too little anaerobic sealing agent is applied, the detorque value does not increase because it is not sufficiently applied to the threads.

The application of the sealing agent increased the torque value, but no fracture or damage of the screw was observed. In the MS group, the remnants after curing in the threads of the screw were removed with a dental explorer, and the remnants inside of the fixture were also easily cleaned. In the HS group, the remaining sealing agent was cleaned with steam spray or ultrasonic cleaning. However, the removal of remaining sealing agent was harder for the HS group than for the MS group. Considering retrievability, there was no damage in the screws when the sealing agents were applied and tightened or loosened.

Moreover, curing is initiated only under anaerobic conditions after screwing. Thus, problems with the prosthesis immediately after implant–prosthesis delivery can be solved easily. Similarly, when tightening, curing starts slowly in an anaerobic environment. Hence, there is no risk associated with rapid tightening of the screw or material hardening before the screw fully tightened. Similar sealing agents such as cyanoacrylate–based bonding agents or silicon sealing agents harden within 5 minutes in an aerobic environment, and therefore, there are restrictions on working time during tightening. In other experiments using sealing agents, an excessively high torque may lead to fracture of the prosthetic screw.[20] Especially when cyanoacrylate-based bonding agents were used, such results were reported.[20] There was no single fracture case in this experiment. In addition, it was found that a consistent torque value below 35 N·cm was exhibited over time. By using anaerobic sealing agents, it means that the results of consistent torque values can be expected.

Sealing agents can act as a physical barrier to any misfit between the implant and the abutment screw, thus reducing microleakage[39] and micro-movements that can cause biological complications such as mucositis or peri-implantitis.[8, 40]

Experimental results show an increase in detorque values due to the anaerobic sealing agents applied to the implant/abutment screw interfaces. This may contribute to the maintenance of preload.[35] However, this study did not consider the effects of moisture in the oral cavity and also the load of stress affecting preload. Therefore, further studies simulating the oral environment are needed for the improvement of the study. Further research on biocompatibility is needed because of the final use in the oral cavity.

V. CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. At 24h, the removal torque values were higher in the groups that used anaerobic sealing agents than in the control group. There were no statistically significant differences between hex abutment and non−hex abutment groups.
2. From 24 to 96h, the HS groups had higher removal torque values than the MS groups.
3. From 24 to 96h, the removal torque values gradually increased with time in the groups using anaerobic sealing agents and non−hex abutments.
4. From 24 to 96h, there were no statistically significant differences in the removal torque values of the groups using anaerobic sealing agents and hex abutments.
5. There were no statistically significant differences in the immediate measurement of the removal torque values in all groups.

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국문초록

혐기성 나사고정제가 임플란트 지대주 나사의 전하중에 미치는 영향

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류 승 범

목 적 : 본 논문의 목적은 임플란트 지대주 나사에 혐기성 나사 고정제를 도포하여 체결한 후 풀 때 풀림토크 값의 차이를 평가하는 것으로, 시간에 따른 풀림토크 값의 차이와 지대주의 형태에 따른 차이를 비교하는 것이다.

방 법 : 외부 육각 연결형 임플란트 고정체(Osstem, Seoul, Korea)를 사용하였고, 동일한 제조사의 티타늄 재질의 지대주와 지대주 나사가 사용되었다. 지대주는 내부 구조가 비육각([NH];non-hex)과 육각([H];hex)형태로 이루어진 것이 사용되었다. 점성과 활성화 시 강도가

다른 혐기성 나사 고정제 2종류([MS]:중강도, Loctite 242; [HS]:고강도, Loctite 243, Henkel, Düsseldorf, Germany)가 사용되었다. 대조군(CG)은 나사고정제를 처리하지 않은 경우로 비육각과 육각 지대주로 나누어 육각 지대주군(H-CG), 비육각 지대주군(NH-CG)으로 구성하였다. 실험군은 대조군 외에 4가지의 군으로 구성하여 지대주의 형태와 혐기성 나사고정제의 종류를 다르게 하여 구성하였다. 4가지의 실험군은 다음과 같다. 중강도의 혐기성 나사고정제와 육각 지대주를 사용한 군(H-MS); 중강도의 혐기성 나사고정제와 비육각 지대주를 사용한 군(NH-MS); 고강도의 혐기성 나사고정제와 육각 지대주를 사용한 군(H-HS); 고강도의 혐기성 나사고정제와 비육각 지대주를 사용한 군(NH-HS). 모든 경우에 대해서 30 N·cm로 체결하였으며, 각 군마다 10개의 시편을 사용하였다. 혐기성 나사 고정제 도포 및 체결 후 즉시 그리고 시간에 따라서 24, 48, 72, 96시간 후에 디지털 토크 측정 장비를 이용하여 풀림 토크 값을 측정하였다. 나사고정제 제조사에서는 24시간후에 제품이 경화된다고 하여, 24시간 후의 각 군의 변화량 비교 시 Welch의 ANOVA 검정 시행하였다. 시간에 따른 변화에 대해서는 이원 반복측정 분산분석을 시행하였다. 이후 Tukey's HSD 검정을 통해 사후 검정 시행하였다. 지대주 나사 체결 후 즉시 풀림토크 값을 측정한 결과는 one-way ANOVA 검정 시행하여 비교하였다. 유의 수준은 5%로 설정하였다.

결 과 : 24,48,72,96시간 후의 각 군에서 평균 풀림토크 값은 다음과 같다. H-CG: 20.3 ± 1.60, 20.1 ± 1.84, 20.0 ± 1.15, 19.8 ± 1.21; NH-CG: 20.2 ± 1.40, 20.0 ± 1.09, 20.1 ± 0.762, 19.8± 1.51; H-MS: 25.0 ± 2.86, 25.1 ± 4.18, 27.1 ± 5.19, 27.3 ± 2.52; NH-MS: 23.5 ± 2.35, 25.9 ± 3.06, 29.2 ± 2.65, 29.6 ± 2.47; H-HS: 32.4 ± 6.75, 32.6 ± 4.34, 31.8 ± 5.26, 31.9 ± 3.76; NH-HS: 19.1 ± 1.05, 28.8 ± 6.06, 31.4 ± 3.63, 33.9 ± 5.37, 35.0 ± 4.50 N·cm. 24시의 각 군 간 비교를 하였을 때 지대주 종류에 관계없이 혐기성 나사고정제를 사용한 군이 대조군보다 풀림토크 값이 컸다. 24시부터 96시까지 측정한 결과, 육각 지대주를 사용한 군은 시간에 따른 풀림토크 값의 통계적 차이가 없었지만, 비육각 지대주를 사용한 군은 시간에 따라 풀림토크 값이 증가하는 경향을 보였다. 각 군에서 체결 후 바로 풀림토크 값을 측정한 결과는 다음과 같다. H-CG: 20.1 ± 0.843; NH-CG: 20.1 ± 0.599; H-MS: 19.6 ± 1.78; NH-MS: 19.7 ± 1.33; H-HS: 19.1 ± 1.07; NH-HS: 19.1 ± 1.05 N·cm. 체결 후 즉시 풀림토크 값을 측정한 결과는 각 군별로 통계적으로 유의한 차이가 없었다.

결 론 : 이번 실험을 통하여 다음과 같은 결론을 얻었다.

1. 24시의 결과에서 혐기성 나사고정제를 사용한 군에서 대조군보다 풀림 토크 값이 높게 나타났고, 육각과 비육각 지대주 간의 통계적으로 유의한 차이는 없었다.
2. 24시부터 96시까지의 결과에서 고강도 혐기성 나사고정제는 중강도 혐기성 나사고정제 보다 높은 풀림 토크 값을 보였다.
3. 24시부터 96시까지의 결과에서 혐기성 나사고정제를 사용한 군에서 비육각 지대주를 사용한 경우 시간에 따라 풀림 토크 값이 증가하는 경향을 보였다.
4. 24시부터 96시까지의 결과에서 혐기성 나사고정제를 사용한 군에서 육각 지대주를 사용한 경우 시간에 따른 통계적으로 유의한 차이는 없었다.
5. 혐기성 나사 고정제를 도포하고 체결한 후 즉시 풀림 토크를 측정한 결과 모든 군에서 통계적으로 유의한 차이는 없었다.

주요어 : 혐기성 나사 고정제, 지대주 나사, 나사 풀림 토크, 전하중

학 번 : 2017-39738

감사의 글

박사과정을 무사히 마치고 이 논문을 시작하여 마무리하기까지 많은 도움을 주신 여러 스승님과 동료, 가족에게 감사의 말씀을 전합니다.

치과보철과 수련 및 대학원 생활에 있어 따뜻한 충고와 조언으로 진료와 연구에 귀중한 가르침을 주신 허성주 교수님께 깊은 감사를 드립니다. 병원 진료와 업무로 바쁘신 와중에도 본 논문을 위하여 많은 지도 편달을 해주셨습니다.

구강악안면외과(原文: 국소의치학)이라는 학문의 깊이와 열정을 일깨워주시고, 이번 논문 심사에도 열과 성을 다해주신 곽재영 교수님과 김성균 교수님께도 깊은 감사를 드립니다.

바쁘신 와중에도 본 논문 심사를 위하여 꼼꼼히 살펴주신 연세대학교 치과대학의 정문규 명예교수님과 치과생체재료과학교실의 임범순 교수님께도 감사드립니다.

항상 격려와 조언을 아끼지 않으신 치과보철학교실의 이재봉 명예교수님, 한중석 교수님, 임영준 교수님, 김명주 교수님, 권호범 교수님, 여인성 교수님, 윤형인 교수님과 치과보철학 교실원 여러분께 이 자리를 빌려 감사의 말씀을 전합니다.

치과보철과 수련 기간부터 지금까지 항상 동고동락하며 서로를 격려해준 동기들과 의국 선후배님, 논문과 관련된 도움을 주신 이유승 누나, 논문 교정에 도움을 준 박세라, 치과 의원 생활과 논문과 관련하여 격려해주신 김동현, 정준 원장님께도 감사드립니다.

마지막으로, 오늘의 제가 있기까지 많은 사랑과 정성으로 보살펴 주시고 지원해주신 부모님께 깊은 감사를 드리며, 제가 하는 모든 일을 응원해주는 누나 류보란, 매형 박상두, 조카 박희승, 박희윤에게도 고마움을 전합니다.

2020 년 8 월

류 승 범